CHAPTER 5 CHIP SEALS

1.0 INTRODUCTION

Chip sealing is the application of a bituminous binder immediately followed by the application of an aggregate. The aggregate is then rolled to embed it into the binder. Multiple layers may be placed and various binder and aggregate types can be used to address specific distress modes or traffic situations.

1.1 TYPES OF CHIP SEAL

There are many different types of chip seals in use by agencies, but only treatments currently being used by Caltrans are discussed in detail in this manual. However, additional treatments not currently in use are also described to promote a broader understanding of other methods. Types of chip seal treatments include:

- **Single Chip Seal**: A single chip seal is an application of binder followed by an aggregate. This is used as a pavement preservation treatment and provides a new skid resistant wearing surface, arrests raveling, and seals minor cracks. Figure 1 illustrates a single chip seal application.

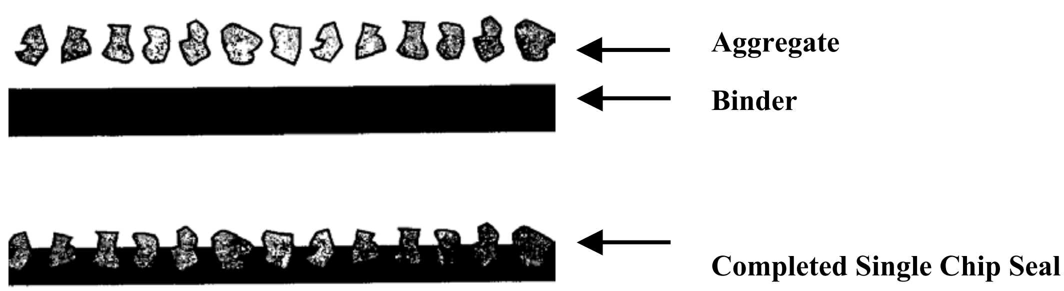


Figure 1: Single Chip Seal

- **Multiple Chip Seal:** A multiple chip seal (or armor coat) is a built-up seal coat consisting of multiple applications of binder and aggregate. As an example, a double chip seal consists of a spray application of binder, spreading a layer of aggregate, rolling the aggregate for embedment, applying an additional application of binder, spreading another layer of aggregate (approximately half the average least dimension of the base coat aggregate), and rolling once more. Sweeping should be done between applications. This process may be repeated, as necessary, to build up a pavement's edges. Multiple chip seals are used where a harder wearing and longer lasting surface treatment is needed. **Caltrans does not use multiple chip seals at this time**. Figure 2 illustrates a multiple chip seal application.

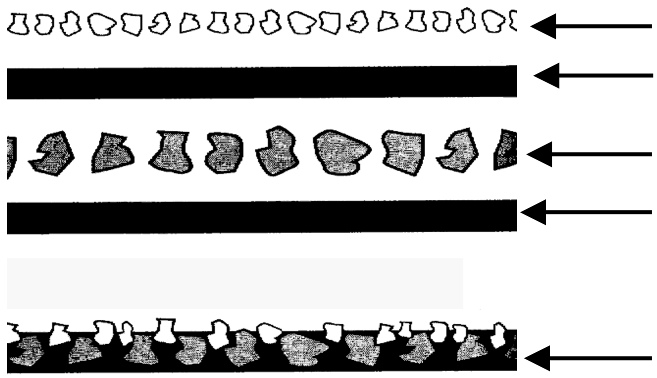


Figure 2: Multiple Chip Seal

- **Stress Absorbing Membrane (SAM) Seal:** A SAM is a single chip seal in which a modified binder (normally asphalt rubber) is applied, followed by a layer of aggregate, and rolling. Binder applications are much higher than those used for conventional chip seals. Generally a SAM has been referred to as being used with AR binders.
- **Stress Absorbing Membrane Inter-layer (SAMI):** A SAMI is a membrane seal that is used to retard the rate of reflection cracking in new overlays. It consists of an application of modified binder followed by a layer of aggregate, spread and rolled. An overlay is then placed over the membrane. If necessary, traffic may be allowed to operate on the SAMI prior to construction of the overlay.

1.2 BINDER TYPES

Binder type varies according to the type of chip seal being used. Binder types include:

- **Asphalt Emulsion:** Polymer-modified emulsions (PME), such as PMCRS-2h, as included in the Standard Specifications, Section 94 (1).
- **Performance-Based Asphalt (PBA) Cements:** Hot applied modified binders that can be placed at cooler temperatures than emulsion binders and can be placed at night. Examples include PBA 6 and PBA 6a binders (2).
- **Asphalt Rubber Binder:** Binders modified with high levels of crumbed tire rubber and a high natural rubber content material. These binders are sprayed hot and require hot chips pre-coated with asphalt. Hot applied AR binders can be placed at cooler temperatures than emulsion binders and can be placed at night.
- **Rejuvenating Emulsion:** These are emulsions modified with rejuvenating oils (and sometimes polymers) that are used to penetrate and soften existing asphalt pavements.

Table 1 lists common binder types and their suitable applications.

Table 1: Binder Type and Suitable Applications

BINDER TYPE	SINGLE	MULTIPLE	SAND	SAM/ SAMI
Asphalt Emulsions	Yes	Yes	Yes	No
PBA	Yes	Yes	Yes	No
Asphalt Rubber	Yes	Yes	Yes	Yes
Rejuvenating Emulsions	Yes	Yes	Yes	No

2.0 PROJECT SELECTION

The general selection of preventive maintenance treatments was covered in Chapter 2. The selection of a pavement for a chip seal project is based on the structural soundness of a pavement and the types of distress that are present. The ability of a treatment to address the current condition of a project is paramount in selecting an appropriate treatment. The main criteria addressed by the varying chip seal types are:

- **Conventional chip seals** are used on structurally sound pavements with minimal cracking.
- **Polymer-Modified Emulsion (PME) chip seals** are used to correct raveling and pavement oxidation.
- **Rubberized chip seals** cure quickly, restore skid resistance on worn surfaces and resist reflection cracking.
- **Special binders** such as asphalt rubber and PBA may be used to address specific distress modes.
- **Distresses such as cracking, flushing, and base failures** cannot be addressed with conventional or hot applied chip seals.
- **Deformation, rutting and shoving** cannot be addressed with chip seals of any kind.

Table 2 lists appropriate binder/chip seal combinations for addressing various distress mechanisms. Generally, chip seals are not used on roads with AADT > 40,000.

The main advantages associated with chip seals include:

- **Improved Skid Resistance**: Chip seals provide good skid resistance.
- **Cost Effective Treatments:** Chip seals are typically cost effective when properly placed on the right type of pavement.
- **Good Durability:** Chip seals wear well and can have long service lives.
- **Ease of Construction:** Chip seals are typically constructed rapidly and cause less disruption to the traveling public than do other treatments that take longer.

Table 2: Binder/Chip Seal Combinations for Addressing Specific Distress Mechanisms

Binder/ Chip Seal Combination	Raveling	Aged Pavements	Bleeding/Flushing	Load Associated Cracks	Water Proofing	Climate Associated Cracks	Heavy Traffic Volumes	Stone Retention	Improve Skid Resistance
PME/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Double	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Sand	Yes	Yes	No	No	Yes	No	No (light)	Yes	No
PBA/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PBA/Double	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PBA/Sand	Yes	Yes	No	No	Yes	No	No	Yes	No
AR/SAM	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Rejuvenating Emulsion	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes

The main disadvantages associated with chip seals include:

- **Cure Time:** PME seals take several hours (depending on the climatic conditions) to reach a stage where they can tolerate unrestricted traffic.
- **Flying Chips:** Chip seals must be swept to remove excess stone to avoid broken windshields and vehicle damage.
- **Noise Considerations:** Chip seals can be noisy to travel on.
- **Weather Considerations:** Cold applied chip seals must be constructed during warm, dry weather and during the daytime only. Hot applied chip seals may be applied in cooler conditions and at night.
- **Performance**: Chip Seals create a rougher surface and are generally not used for parking lots. Chip seals do not improve ride quality.

Other limitations of chip seals include:

- **PME Seals:** These are not normally suitable for intersections or high stress areas.
- **PBA Seals:** These cure quickly, but are not suitable for very high stress areas due to their low initial shear strength.

3.0 DESIGN AND SPECIFICATION

3.1 MATERIAL SPECIFICATIONS

3.1.1 Binders

Binders are selected based on their performance characteristics. They need to provide good adhesion and or stickiness. Polymer Modified emulsion binders usually contain latex additives, although other elastomeric polymers are often used. The purpose of the polymer is to improve stone retention during the early life of the treatment and to increase the softening point of the binder after cure (i.e., the temperature at which the binder changes phase from being primarily solid to being primarily fluid). The general-purpose base binder is an 85/100-penetration grade asphalt cement. This base binder mostly controls low temperature properties. For cold climates, a softer base asphalt (e.g. an 120/150 penetration grade) may be warranted. For hot climates, a harder base binder (e.g., a 40/50 penetration grade) might be considered.

PBA's are, by definition, performance-based. This means that they may contain a range of materials to enhance certain characteristics. PBA-6 and PBA-6a usually contain elastomeric polymers, which increase the binder's softening point and improves its crack resistance. Asphalt rubber binders contain high levels of crumbed tire rubber and high natural rubber materials, which increases the softening point of the binder, improves stone retention, and produces good resistance to reflection cracking. In general, the base binder largely determines the low temperature properties; softer bases should be used in lower temperature areas. Selection of a particular binder type should also take into consideration climatic conditions, traffic levels, and types of loads associated with the project (e.g., consideration of snow plow use, AADT, and percent trucks).

Emulsion specifications are included in Section 94 of the Standard Specifications (2) and related SSP's as discussed in Chapter 1 of this guide.

3.1.2 Aggregates

For chip seals, the best performance is obtained when the aggregate has the following characteristics:

- Single-sized, if possible.
- Clean.
- Free of clay.
- Cubical (limited flat particles).
- Crushed faces.
- Compatible with the selected binder type.
- Aggregates must be damp for emulsion use, but must be dry for use with hot binders.

The specifications for aggregates used in chip seals are included in Section 37-1.02 of the Standard Specifications.

3.2 CHIP SEAL DESIGN

Properly designed chip seals have proven to be cost effective in sealing pavements and providing a new riding surface with enhanced frictional characteristics. Many countries have developed rational chip seal design methods and, as a result, have used chip seals on major highways. Caltrans does not currently employ a formal design process for Chip Seals. The methods currently used are based on experience and do not address adjustments for the factors identified below. This section is included for information purposes only and to provide a foundation for an improved design process.

The basics of chip seal design are straightforward, as the binder application rate and the aggregate application rate are the only variables of major importance to consider. However, to correctly calculate these rates requires an understanding of the materials and the surface on which they are to be applied. Additional factors to consider include traffic, climate, and existing surface condition. The determination of the proper binder and aggregate application rates is discussed in greater detail in the following two sections. The design of multiple seal coats is also briefly described. However, sand seals and sandwich seals are designed strictly from experience and are not included in this discussion of design procedures.

3.2.1 Binder Application

In chip seal design, the residual binder application rate is the most important factor affecting seal performance. Enough binder must be present to hold the aggregate in place, but not so much that the binder fills, or is forced by traffic action to cover the aggregate. The proper amount of binder ensures that the desired surface texture is maintained. Chip seal design is not like hot mix asphalt design, in that film thickness is not as applicable a concept. Binder application rates are determined based on the average least dimension of the aggregate, as well as other aggregate properties such as shape, density, absorption and grading. The optimum binder content also depends on how much binder flows into existing voids in the pavement, and how much binder is already present at or near the pavement surface.

The McLeod method is the most common design method for chip seals (6); however it is not used by Caltrans. This method assumes that 70% of the voids in the aggregate must be filled (i.e., 70% embedment). In some states, this is adequate and has been adopted as the standard; however, modifications can be made for varying project conditions.

A more detailed discussion on this design method can be found in “A General Method of Design for Seal Coats and Surface Treatments” by N.W. McLeod. The McLeod method also assumes the use of a cubical, single-sized aggregate. This may not always be the case (e.g., California specifications specify graded aggregates). The main modification for graded aggregates is determining a median aggregate size (50% passing). The aggregate shape must also be examined; this is done by measuring the flakiness index (3). The average least dimension (ALD) can then be determined using the following equation (3):

$$H = [M / 1.139285 + (0.011506)*FI] \qquad (4.1)$$

where: *H = Average Least Dimension, or (ALD)*
M = Median Particle Size
FI = Flakiness Index

ASTM C29 is used to measure the loose unit weight. This approximates the voids in the loose aggregate when it is dropped onto the pavement. The voids in this state are 50% for cubical, single-size aggregate and lower for graded aggregate. It is assumed that once rolled a cubical aggregate will reduce its unit weight to a point where the voids content is 30% and finally to 20% once trafficked. These assumptions are adjusted when using graded aggregates. Figures 2 through 4 illustrate the average least dimension (ALD) concept, along with the effects of flakiness and changes in voids based on compaction.

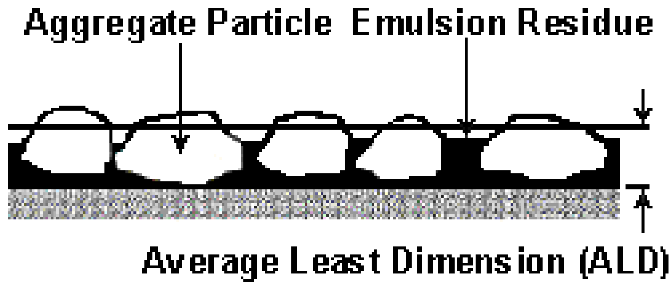


Figure 2: Illustration of ALD (4)

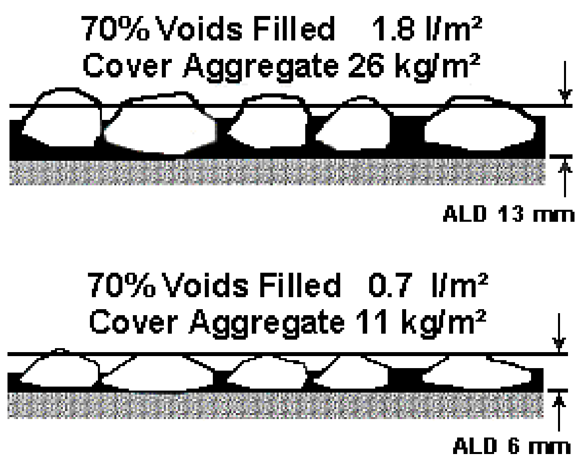


Figure 3: Illustration of Flakiness of Aggregates (4)

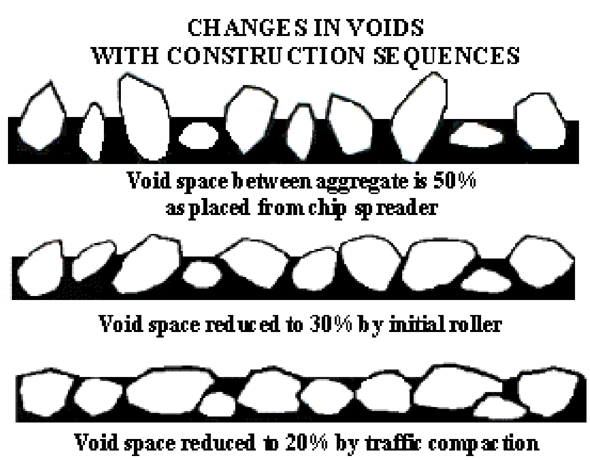


Figure 4: Effects of Compaction on Voids in Cubical Aggregate (4)

The voids in loose aggregate may be calculated using the following equation (3):

$$V = 1 - W / 1000*G \quad (4.2)$$

where: *V = Voids in the Aggregate*
W = Loose Unit Weight of the Aggregate (in ASTM use 29kg/m^3)
G = Bulk Specific Gravity of the Aggregate (usually determined from local information or measured)

Most design methods calculate the specific requirements for each job by considering the required corrections in addition to the basic application rate (the rate designed to result in 70 percent embedment). One method for estimating the binder content is as follows (3):

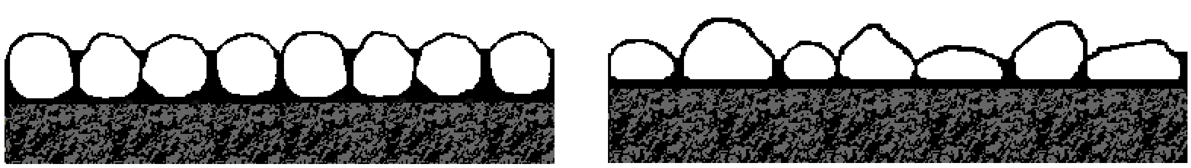
$$B = [0.40(H) \times T \times V + S + A + P] / R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.3)$$

where:
B = Binder Content (l/m^2)
H = ALD (m) – (See Page 5.7)
T = Traffic Factor – (See Table 3)
V = Voids in Loose Aggregate (%) – (See Equation 4.2)
S = Surface Condition Factor (l/m^2) – (See Table 5)
A = Aggregate Absorption (l/m^2) – (See CTM 303)
P = Surface Hardness Correction for Soft Pavement (L/m^2) – (See Table 6)
R = Percent Binder in the Emulsion (%) – (See Manufacturer)

For projects in areas maintained by snowplows, the binder content is calculated using both the median particle size and the ALD. The average of these two results is used as the starting application rate in these areas.

Corrections to the basic application rate for the aggregate address variables that affect the level to which it becomes embedded in the binder. The corrections are ultimately applied to the calculation of the binder application rate. These variables include:

- **Aggregate Characteristics:** Important aggregate characteristics include absorption and shape. Corrections for absorption are based on experience and the characteristics of the local aggregates. Chip shape effects are variable: rounded chips leave greater voids and do not interlock and are not recommended. This type of chip also requires additional binder. Non-uniform sized aggregates produce uneven surfaces. Figure 5 illustrates both rounded and non-uniform chip applications.



a) Rounded **b) Non-Uniform**

Figure 5: Aggregate Shape Characteristics (5)

- **Traffic Volume:** This factor accounts for the role that traffic volumes play in achieving the ultimate embedment of 80 percent (20 percent void space). The traffic factor is lower for higher traffic volumes and higher for lower traffic volumes. Table 3 lists the application rate correction factors associated with varying traffic levels.

Table 3: Traffic Factors (3, 6)

VEHICLES/DAY	0-100	101-500	501-1000	1001-2000	>2000
Correction Factor	0.85	0.75	0.70	0.65	0.60

- **Loss of Aggregate Due to Traffic (Traffic Whip-Off):** A traffic whip-off correction accounts for the effects of traffic operations on removing aggregates from newly chip sealed roads. Reasonable values for losses are 5% for low volume roads and residential streets and 10% for high-speed roads and highways. Table 4 lists road types and associated whip-off correction factors.

Table 4: Road Type and Associated Aggregate Loss (Whip-Off) Factor (3)

ROAD TYPE	PERCENT WASTAGE (%)	WHIP-OFF FACTOR (E)
Rural & Residential	5	1.05
Higher Volume Roads	10	1.10
State Highways	15	1.15

- **Existing Pavement Condition:** Existing pavement conditions play a very important role in determining the optimum binder content. A smooth surface will require less binder than will a rough or porous surface. Table 5 details the correction factors associated with various existing pavement conditions.

Table 5: Correction Factors Associated with Existing Road Conditions (3)

EXISTING PAVEMENT	CORRECTION (l/m^2)
Black, flushed asphalt	-0.04 to -0.27 (Depending on severity)
Smooth, non-porous or smooth	0.00
Slightly porous and oxidized or matte	+0.14
Slightly pocked, porous, and oxidized	+0.27
Badly pocked, porous, and oxidized	+0.40

- **Embedment:** Aggregates may be punched or embedded into soft pavement surfaces by roller compaction and traffic. Table 6 provides corrections based on surface hardness and related traffic volume using a Ball Penetrometer test (7).

Table 6: Binder Content Correction Based on Surface Hardness and Related Traffic Volume (7)

SURFACE HARDNESS	TRAFFIC VOLUME (AADT PER LANE)				
	150 -300	300 -625	625 -1250	1250 -2500	>2500
Hard (Ball Value 1 – 2)	Nil	Nil	Nil	-0.1 l/m^2	-0.2 l/m^2
Medium (Ball Value 3 – 4)	Nil	Nil	-0.1 l/m^2	-0.2 l/m^2	-0.3 l/m^2*
Soft (Ball Value 5 – 8)	-0.1 l/m^2	-0.1 l/m^2	-0.2 l/m^2	-0.3 l/m^2	-0.4 l/m^2*
*Where embedment allowances of 0.3 l/m^2 or more are indicated, consideration should be given to alternative treatments such as multiple chip seal (armor-coating) with higher quality materials rolled into the surface, or the use of a primer seal/ prime and seal with a small aggregate in order to provide a platform on which a larger aggregate seal may be placed.					

3.2.2 Aggregate Application

Calculation of the design aggregate application rate is based on determining the amount of aggregate needed to create an even, single coat of chips on the pavement surface. Though not used by Caltrans, the amount of cover aggregate required can be determined using the following equation (3):

$$C = (1 - 0.4V) \times H \times G \times E \quad \text{……………………………………..(4.4)}$$

where:

C = Cover Aggregate (kg/m^2)
V = Voids in Loose Aggregate (%)
H = ALD (mm) – (See Page 5.7)
G = Bulk Specific Gravity – (See CT 206 & CT 208)
E = Wastage Factor (%)

Equation 4.1 is used to calculate H (average least dimension) and Equation 4.2 is used to calculate V (voids in loose aggregate). The bulk specific gravity of coarse and fine aggregates, G, can be determined using CT 206 and CT 208, respectively. The wastage factor (E) is to account for whip-off and handling and is normally estimated by the designer based on experience with local conditions. While other design methods are available, Equation 4.4 provides a good starting point and covers most situations. It requires that the user consider the attributes of the surface being sealed and the conditions to which it will be subjected, which are both very important.

The design of multiple coat seals is based on the same concepts as the single chip seal. First, a design is performed for each layer as if it were the only layer in the system. Next, the following three additional rules are applied as follows: 1) the maximum nominal top size of each succeeding layer of cover aggregate should be no more than half the size of the previous layer's aggregate; 2) no allowance is made for wastage; and 3) except for the first application, no correction is made for the underlying surface texture. The amounts of binder determined for each layer of aggregate are added together to calculate the total binder requirement. For two-layer chip seals, 40% of the total binder requirement is applied for the first layer of aggregate and the remaining 60% is applied for the second layer.

3.2.3 Application Rate for Polymer Modified and Asphalt Rubber Modified Seals

For asphalt rubber (e.g., SAMI's), typical binder application rates of 2.2 to 2.5 l/m^2 (0.55 to 0.65 gal/yd^2) are used. For asphalt rubber seals, the binder application rate is significantly higher compared with the base application level calculated for unmodified binder. The higher binder rates are possible due to the higher viscosity of these binders. Application of cover aggregate should be the same in a SAM or SAMI to avoid damage to the membrane due to pick-up by the construction equipment or when the membrane is opened to traffic.

Caltrans practices for these materials are summarized in their standard specifications, Section 37-1.05.

4.0 CONSTRUCTION

4.1 CONSTRUCTION PROCESS

The sequence of construction events is as follows:

1. Project Preparation
2. Surface Preparation
3. Binder Application
4. Aggregate Spreading
5. Rolling
6. Sweeping (Brooming)

Figure 6 illustrates the construction process from binder application through final sweeping. Details of the construction process are provided in the following sections.

4.2 PREPARATION

Preparation of the surface is critical to the performance of the chip seal. Areas of the pavement exhibiting structural failures (such as potholes and deteriorated patches) should be addressed by the removal or patching and sealing of the failed area. Avoid the use of cold mix for patching prior to applying the chip seal. Finally, the prepared surface must be clean, dry and free of any loose material before applying the binder. Preparation for a chip seal project typically includes:

- Milling of the surface (if there is extensive loose material or areas of bleeding that must be removed).
- Crack sealing or filling of cracks that are likely to reflect through the chip seal (see Chapter 3).
- Patching any deteriorated areas or dig outs where required (see Chapter 4).
- Cleaning or brooming any loose material from the pavement surface, such as areas of raveling.
- Removing pavement markers and delineators.

If the patched areas are generally more porous than the rest of the pavement, a tack coat prior to sealing may be required. Known shaded areas that seldom get sunlight (i.e. under bridge decks) may need a tack coat as well to prevent rock loss.

a) Binder Application

b) Spreading of Aggregate

c) Rolling

d) Sweeping

Figure 6: Construction Process for Chip Seals

4.2.1 Materials

A work site needs to contain a facility for storing aggregate and binder. Generally, binders are trucked directly from the manufacturer and off loaded for use. However, situations arise when distance and weather create the need for off site storage. The site should be chosen well in advance of project start-up. The aggregate stockpile should ideally be placed on a sloped and paved surface, but at least on a sloped surfaced to promote drainage of the stockpile. It should also ideally be protected from contamination with foreign material. Once stockpiled, the aggregate should not be moved until it is to be transported to the road being chip sealed. Following project completion, any remaining aggregate must be removed from the stockpile site and the site restored to its original condition before being used as a stockpile site. The methods for storing and handling binders and aggregates, for chip seals, is the same as those for terminal storage as outlined in Chapter 1 (Introduction) of this guide.

4.2.2 Weather Conditions

On the actual day when chip seals are constructed the weather should be clear and warm. In general, pavement surface temperatures should be 10°C (55°F) and rising, and the humidity should be 50% or lower. Wind may cause the emulsion spray to be diverted and compromise uniformity of application rate. A gentle breeze will assist in accelerating cure times. Any rainfall immediately before, during or after the construction of the PME chip seal will contribute to failure of the treatment. Thus, placement of chip seals should be avoided during such conditions. The actual requirements vary for different binder types and are included in the Caltrans specifications.

4.2.3 Traffic Control

The Resident Engineer (RE) examines and approves the contractor's traffic control plan prepared in accordance with the Caltrans Safety Manual (8) and the Caltrans Code of Safe Operating Practices (9). The signs and devices used must match the traffic control plan. The work zone must conform to Caltrans practice and requirements set forth in the Caltrans Safety Manual and the Caltrans Code of Safe Operating Practices. All workers must have all required safety equipment and clothing.

After chipping, pilot cars should be used for between 2 and 24 hours to ensure that traffic speed is limited to approximately 30 kph (20 mph).

4.3 JOINTS

Chip seal passes should begin and end on felt paper or equal. This ensures that the transverse joints are clean and sharp. Longitudinal joints may be made with an overlap. In this process a wet edge (i.e., one without an application of aggregate) of 75 to 100 mm (3 to 4 in) is left (not in a wheel path) and the next run overlaps this wet edge. The chip distributor then covers the whole run to the pavement's edge. Figure 7 illustrates the layout of felt paper at the end of a project lane.

4.4 SPRAYING EQUIPMENT

The spray distributor is the most important piece of equipment in the chip seal process. Its function is to uniformly apply the binder over the surface at the designed rate. Typically, spray distributors (boot trucks) are truck mounted as shown in Figure 8, but trailer units have also been used. A distributor should have a heating, circulation, and pumping system, along with a spray bar, and all necessary controls to guarantee proper application.

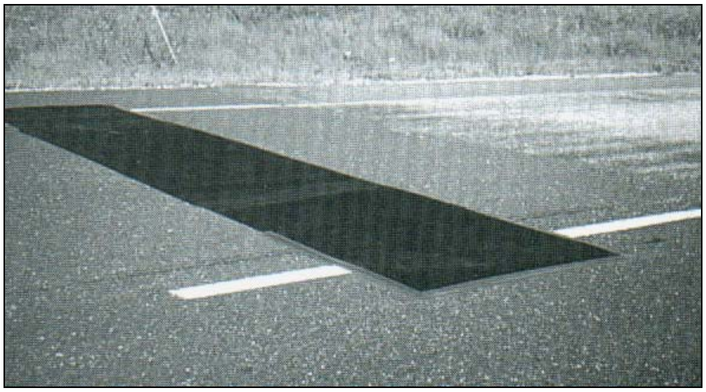


Figure 7: Start and Stop Passes on Roofing Felt (Transverse Joints)

Figure 8: Spray Distributor

4.4.1 Distributor Preparation

The steps associated with preparing the distributor include:

a) Calibrate the distributor by spraying a pre-weighed area of carpet (backed with a waterproof layer) and subtracting the initial weight from that of the sprayed carpet, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate. See CT 339 for calibration procedures.
b) Blow the spray nozzles to ensure there are no blockages and checking the nozzle angles (see Figure 9) to ensure they spray at an angle 15 to 30 degrees from the spray bar axis. Often, the outer-most nozzles will be turned in to give a sharp edge with no over spray.
c) Check the distributor bar's height. The height is usually set so that a double or triple overlap is obtained as illustrated in Figure 10.
d) Check the distributor bar's transverse alignment to ensure it is closely perpendicular to the centerline of the pavement
e) Check the binder temperature to ensure it is in the appropriate range for proper application. Chip seal emulsion should be between 40 and 85 °C (104 and 185°F) (6).
f) Ensure an adequate supply of binder is available.

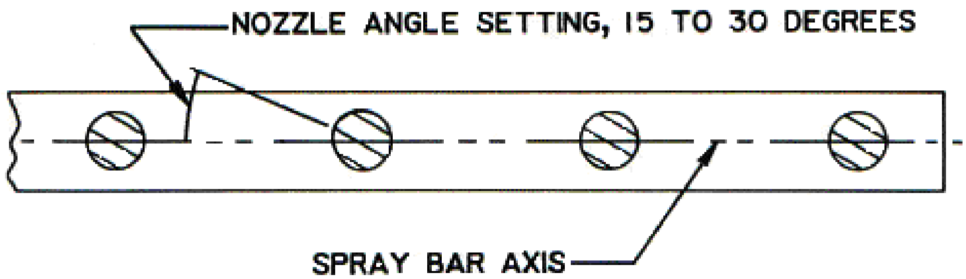


Figure 9: Spray Bar with Nozzle Arrangement (6)

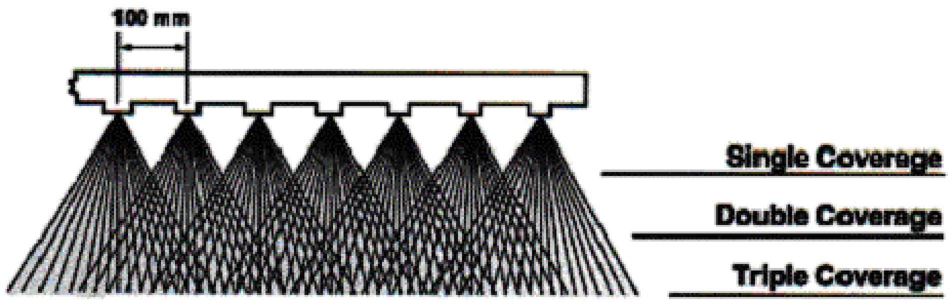


Figure 10: Spray Bar Height Arrangements (6)

Visual checks should be made throughout the spraying process to ensure that the spray bars are clean and are spraying even fans. There should be no streaking of binder visible on the surface. If streaking occurs, the operation should be stopped to recheck proper functioning of the spray bar as well as proper binder temperature. The inspector should check application rates frequently. The application rate can be checked using the calibration method mentioned above or using the alternative method outlined in Appendix A of this chapter. The method above is recommended for equipment calibration while the alternative method is appropriate for quick spot-checking during construction.

4.4.2 Chip Spreader

Chip spreaders must be able to spread an even coating of aggregate one layer thick over the entire sprayed surface. Figure 11 shows a typical chip spreader.

Figure 11: Chip Spreader

Prior to applying aggregate on a project, the following steps should be taken:

a) Calibrate the spreader by spreading chips over a pre-weighed area of carpet and subtracting the initial weight from that of the carpet with chips spread onto it, then dividing the difference by the area of the carpet. Although this is the responsibility of the contractor, the inspector should verify that the spreader is applying the aggregate at the correct application rate.
b) Ensure all gates in the spreader open correctly.
c) Ensure the spreader applies the aggregate is an even, single-layer thickness.
d) Ensure that the spreader is not leaving piles of aggregate and is not spreading too thick a layer. Too thick a layer of aggregate can result in the aggregate being crushed under rollers or by traffic, compromising the seal. Too thick a layer of aggregate can also result in the lever and wedge effect illustrated in Figure 12, which also compromises the seal.
e) Ensure an adequate supply of aggregate is available prior to applying the binder.
f) Ensure proper moisture content of aggregate for PME chip seals.

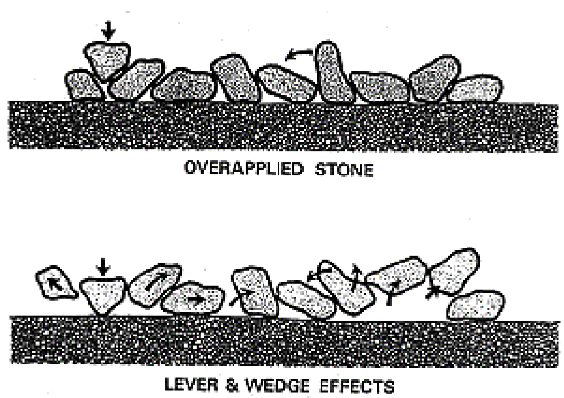


Figure 12: Lever and Wedge Effect (5)

4.4.3 Chip Spreading Process

The application of aggregate should follow the binder application by no more than 90 seconds in order to obtain the best possible aggregate retention. A good visual check is that the spreader should be no more than 30 m (100 ft) behind the distributor truck. The first chip spreading pass is usually done against traffic to allow good centerline match up. The direction for spreading is chosen mostly to minimize truck movements on the fresh oil.

Visual checks of the spreading include checking that the aggregate does not roll or bounce when applied. The flow of aggregate should also be checked. If a wave of binder forms in front of the blanket of aggregate, the binder application may be too heavy. The scalping screen should also be checked for build up of clay or other contaminants. If such contamination is heavy, it may be necessary to re-screen the stockpile. The spread pattern should be even without ripples or streaks. If ripples or streams occur, the spreading gates may need to be lowered and the machine slowed down.

4.5 HAUL TRUCKS

Haul trucks are responsible for providing a continuous supply of binder to the site and aggregate to the spreader. Haul trucks should be in good mechanical condition. Leaking haul trucks can compromise the seal binder. Single axle trucks carry between 4,500 and 6,350 kg (5 and 7 tons) and trucks with tandem axles between 9,000 and 12,700 kg (11 and 14 tons). For this reason, trucks with tandem axles are the preferred. The increased capacity requires fewer hook ups resulting in less chance for spillage and a more efficient operation.

Tires on the trucks should be examined for binder pick up. If pick up occurs, it may severely damage the mat. Tires should be cleaned and sanded. Trucks should not drive on the new surface unnecessarily and should never brake sharply. When driving on the fresh mat, wheel paths should be staggered to assist in embedding the aggregate uniformly. When pulling away from the spreader, trucks should move smoothly and slowly to prevent wheel spin and mat damage. Trucks shall not be allowed to lose or dump chips when pulling away from the chip spreader. No sharp turning movements or high speeds should be allowed on a newly constructed chip seal.

4.6 ROLLING

The function of the roller is to embed the aggregate into the binder and orient it into an interlocking mosaic. This is initially accomplished with pneumatic rollers as shown in Figure 13; compaction applied by traffic finish the process. Rolling should be expedited in hotter weather to ensure proper embedment of the aggregate. Steel rollers are not normally recommended because they can crush the aggregate.

Figure 13: Pneumatic (Rubber Tired) Roller

The important variables when rolling chip seals are:

- Contact pressure
- Number of passes and pattern
- Speed
- Smoothness of tires
- Adequate number of rollers

Contact pressure depends on the vehicle weight, the number of tires, tire size and rating, and the tire inflation pressure. Rollers that can be ballasted are very useful in assuring sufficient contact pressure. The ballasted weight should be 4500 to 5400 kg (4 to 6 tons), with a corresponding tire pressure of 600 kPa (87 psi). Tires must have a smooth tread, should not vary more than 50 kPa (7 psi) in pressure, and should not wobble during operation.

Rollers should follow aggregate spreading by no more than 150 m (500 ft) and should not be operated at more than 10 kph (6 mph). The rolling pattern will depend on the number of rollers used. A minimum of two rollers should be used to cover the full width of the chip spreader. When two rollers are used, three passes are sufficient; one forward, one in reverse, and the final pass extending into the next section.

4.7 BROOMING

Brooming is required before, after, and sometimes during the chip seal operation. Before applying the chip seal the pavement must be swept clean of dust and debris. During a multi-coat sealing operation excess aggregate shall need to be broomed off between coats. After the chip seal has been constructed, excess aggregate must be broomed off to minimize whip-off by traffic.

Brooming is done using rotary brooms with nylon or steel bristles or with vacuum mobile pickup brooms. The broom should not be worn, and should not be operated in such a manner that removes embedded aggregate. Figure 14 illustrates a typical brooming operation.

Mobile pickup brooms are usually capable of picking up aggregate and storing it. Sometimes so-called “kick brooms” are used. These brooms move the aggregate into a windrow so that is can be collected, but they often generate dust and may sweep aggregate into watercourses or gutters. Figure 15 illustrates a typical kick broom.

Brooming can generally be done within 2 to 4 hours after sealing. Hot applied chip seals can be swept within 30 minutes while conventional chip seals can be swept in 2 to 4 hours. A flush coat shall be applied after brooming to eliminate further rock loss and improve durability prior to opening the pavement to uncontrolled traffic.

Figure 14: Brooming Process, Shown on a Shoulder Seal

Figure 15: Kick Broom

5.0 FIELD TESTING

Most tests of constructed chip seals are empirical and provide the user an indication of what extra adjustments must be made on the job site. Though not used by Caltrans, the Ball Penetrometer Test (7) and the Sand Patch Test (ASTM E965) are useful methods for checking the original pavement and the final seal. In the Ball Penetrometer Test, a ball is hammered on the pavement surface using a Marshall hammer a predetermined number of times. The amount of ball penetration into the existing surface is an indicator of the pavement's hardness with typical values ranging from 0 to 0.5 mm. The Sand Patch Test gives surface texture information for classifying surface type or examining seals with typical texture depths ranging from 1 mm to 2.5 mm depending on the aggregate size. Figure 16 illustrates a technician performing the Ball Penetrometer Test and the Sand Patch Test.

a) Ball Penetrometer Test

b) Sand Patch Test

Figure 16: Field Test Methods

6.0 TROUBLESHOOTING

This section provides information to assist maintenance personnel in troubleshooting problems with chip seals. The guide, along with a related table on problems and solutions, address common problems encountered during the course of chip seal projects.

6.1 TROUBLESHOOTING GUIDE

The troubleshooting guide presented in Table 7 associates common problems to their potential causes. In California, the most common problem is flushing.

In addition to the troubleshooting guide, Table 8 lists some commonly encountered problems and some recommended solutions.

Table 7: Troubleshooting Chip Seal Problems (Hot/Emulsion/Asphalt Rubber)

CAUSE	PROBLEM										
	EXCESSIVE LOSS OF AGGREGATE	CRUSHING OF AGGREGATES	PICKUP OF BINDER	ADHESION PROBLEMS	RAVELING OF AGGREGATES	STREAKING OF BINDER	TRANSVERSE PATCHES	FLUSHING	FAILURE IN SHADE	POLISHING OF AGGREGATE	POOR MOSAIC OF FINISHED MAT
Poor Traffic Control	●		●		●				●		●
Poor Equipment	●		●		●		●	●	●		●
Spray Temperature	●		●		●	●	●		●		●
Vehicle Speeds	●				●	●	●	●	●		●
Distributor Nozzles	●				●	●		●	●		
CLIMATIC CONDITIONS											
Cold Surfaces	●			●	●				●		●
Wet	●			●	●				●		●
Windy	●			●	●				●		●
BINDER											
Wrong Binder	●		●	●	●	●		●	●		●
Too Little Binder	●			●	●				●		●
Too Much Binder	●		●					●			●
AGGREGATE											
Too Little	●		●					●			●
Too Much	●	●		●	●		●		●		●
Wet	●			●	●			●	●		●
Dirty	●			●	●				●		●
Quality	●	●		●	●				●	●	
Wrong Size	●				●			●	●	●	●
PRECOAT											
Too Little	●			●	●				●		
Too Heavy	●				●						

Table 8: Common Problems and Related Solutions

PROBLEM	SOLUTION
Streaking or drill marks in the emulsion	▪ Ensure emulsion is at correct application temperature. ▪ Ensure the viscosity of the emulsion is not too high. ▪ Ensure all the nozzles are at the same angle. ▪ Ensure the spray bar is not too high or too low. ▪ Ensure the spray bar pressure is not too high or too low. ▪ Ensure nozzles are not plugged.
Exposed emulsion after chip application	▪ Ensure the chip spreader gate is not clogged or malfunctioning. ▪ Ensure the chip spreader is covering all the binder
Excessive chips/Many chips with small amounts of emulsion	▪ Ensure the chip spreader gate is not malfunctioning or chipper head is not overloaded. ▪ Lower the chip application rate.
Uneven chip application	▪ Re-calibrate the chip spreader; ensure all spreader gates are set the same.
Emulsion on the top of chips	▪ Ensure the chip spreader is not operating too fast. ▪ Ensure trucks, rollers, and pilot cars are operating correctly at low speeds.
Chips being dislodged	▪ Ensure the emulsion application is not too light. ▪ Ensure the chips are not dirty or dusty. ▪ Ensure the traffic or equipment speeds are not too high. ▪ Ensure brooming does not occur before the emulsion is properly set.
Emulsion bleeding or flushing	▪ Ensure the emulsion application is not too high. ▪ Ensure the aggregate application is not too low.
After brooming, loss of chip at centerlines	▪ Check centerline procedure. ▪ Check binder application rate.
Excessive splattering of the emulsion	▪ Lower the spray pressure.

7.0 REFERENCES

1. California Department of Transportation, “Standard Specifications”, Sacramento, California, 1999.

2. California Department of Transportation, “Standard Special Provisions Asphalt”, S8 M20, 1999.

3. Jannisch, D.W., Gaillard F.S., “Minnesota Seal Coat Handbook: Final Report”, Minnesota Department of Transportation, December 1998.

4. Federal Highway Administration, U.S. Department of Transportation, “An Overview of Surface Rehabilitation Techniques for Asphalt Pavements”, FHWA-PD-92-008, Washington, DC, 1992.

5. South Australian Department of Transportation, “Bituminous Sealing Manual”, 1995.

6. McLeod, N.W., “A General Method of Design for Seal Coats and Surface Treatments”, Proceedings of the Association of Asphalt Paving Technologists, Volume 38, St. Paul, Minnesota, 1969.
7. Austroads, “Design of Sprayed Seals”, Surry Hills, New South Whales, Australia, 1990.

8. California Department of Transportation, “Caltrans Safety Manual”, Chapter 12, Sacramento, California, 1998.

9. California Department of Transportation, “Caltrans Code of Safe Operating Practices”, Chapter 12 and Appendix C, Sacramento, California, 1999.

10. Stevenson, J., “Maintenance Chip Seal Manual”, Montana Department of Transportation, 1996.

11. Holleran, G., “Chip Seal Design”, California Chip Seal Association Annual Meeting, January, 2001.

12. Federal Highway Administration, U.S. Department of Transportation, “Manual on Uniform Traffic Control Devices (MUTCD)”, Millennium Edition, Washington, DC, 2002.

13. TRH 3 Committee, “Design of Bituminous Seals”, South Africa Roads Board, 2002.

14. The Asphalt Institute, “A Basic Asphalt Emulsion Manual”, Manual Series No. 19, Lexington, Kentucky, 1999.

APPENDIX A

SUGGESTED FIELD CONSIDERATIONS FOR CHIP SEALS

The following field considerations are a guide through the important aspects of performing a chip seal project. The various tables list items that should be considered in order to promote a successful job outcome. The answers to these questions should be carefully evaluated before, during and after construction. The appropriate staff to do this will vary by job type and size, and some topics may need attention from several staff. The field supervisor should be acquainted with its contents. Responses to the questions in these tables are not meant to form a report, but rather to call attention to important aspects and components of the chip seal project process. Some information is product-specific and contained in the relevant standard specifications, standard special provisions, or special provisions.

PRELIMINARY RESPONSIBILITIES	
PROJECT REVIEW	▪ Is the project a good candidate for a chip seal? ▪ How much rutting is present? ▪ How much and what type of cracking exists? ▪ Is crack sealing needed? ▪ How much bleeding or flushing exists? ▪ Review project for bid/plan quantities.
DOCUMENT REVIEW	▪ Bid specifications. ▪ Special provisions. ▪ Construction manual. ▪ Traffic control plan (TCP).
MATERIALS CHECKS	▪ The type of binder to be used is compatible with the chips? ▪ The binder is from an approved source (if required)? ▪ The binder and aggregate have been sampled and submitted for testing (if required)? ▪ All chips are close to the same size? ▪ The chips are clean and free of excess fines? ▪ The chips used with emulsions are in a surface-damp condition? ▪ Is the emulsion temperature within application temperature specification?
SURFACE PREPARATION	▪ Is the surface clean and dry? ▪ Have all pavement distresses been repaired and sealed? ▪ Has the existing surface been inspected for drainage problems? ▪ Have pavement markers been removed and temporary markers placed?

EQUIPMENT INSPECTIONS	
BROOM	▪ The bristles are the proper length? ▪ The broom can be adjusted vertically to avoid excess pressure? ▪ Are water misters operable?
DISTRIBUTOR	▪ Is the spray bar at the proper height? ▪ Are all nozzles are uniformly angled 15 to 30 degrees from the spray bar? ▪ Are all nozzles free of clogs? ▪ Is the spray pattern uniform and does it properly overlap (double or triple)? ▪ Is the application pressure correct? ▪ Is the distributor properly calibrated and correct size nozzle tips installed?
CHIP SPREADER	▪ Do the spreader gates function properly and are their settings correct? ▪ Is the scalping screen in good condition? ▪ Is the chip spreader's calibration uniform across the entire chipper head? ▪ Are the truck hook-up hitches in good condition?
ROLLERS	▪ What type of roller will be used on the project (pneumatic-tired roller recommended)? Do rollers meet weight requirements? ▪ Does the roller tire sizes, ratings, and pressures comply with the manufacturer's recommendations and specifications? ▪ Are the tire pressures the same on all tires? ▪ Do all tires have a smooth surface?
HAUL TRUCKS	▪ Is the truck box clean and free of debris and other materials? ▪ Is the truck hook-up hitch in working order? ▪ Is a truck box apron or extension required for loading the chip spreader?
WEATHER REQUIREMENTS	▪ Do the specifications describe a range of dates when chip sealing can be done? ▪ Air and surface temperatures have been checked at the coolest location on the project? ▪ Air and surface temperatures meet agency requirements? ▪ Are high winds expected? High winds can create problems with the emulsion application. ▪ Will the expected weather conditions delay the breaking of the emulsion? High temperatures, humidity, and wind will effect how long the emulsion takes to break. ▪ The application of emulsion should not begin if rain is likely within 24 hours.

<table>
<tr><th colspan="2">EQUIPMENT INSPECTIONS</th></tr>
<tr><td>DETERMINING APPLICATION RATES</td><td>

- Agency guidelines and requirements have been followed?
- Has a chip seal design been done?
- Is the surface oxidized or porous? More oil is applied to dried-out and porous surfaces.
- Is the traffic volume on the road low? More oil is applied on roads with low traffic volumes.
- Is the surface smooth, non-porous, or bleeding? Less oil is applied to smooth, non-porous, and asphalt-rich surfaces.
- Is the traffic volume on the road high? Less oil is applied on roads with high traffic volumes.
- Is there a salt and pepper appearance after the chips have been applied?

</td></tr>
<tr><th colspan="2">BINDER CALIBRATION CONSIDERATIONS</th></tr>
<tr><td>CHECKING APPLICATION RATES</td><td>

Binder – Method A (Recommended for Calibration)

- The weight of a 0.84 m^2 (1yd^2) carpet, pan, or non-woven geotextile material is recorded.
- The carpet, pan, or non-woven geotextile material is placed on the road surface.
- The distributor applies oil over the carpet, pan, or geotextile material.
- The weight of the carpet and oil, pan and oil, or geotextile material and oil is recorded.
- The weight of the carpet, pan, or geotextile material without oil is subtracted from the weight of the carpet, pan, or geotextile material with emulsion.
- The weights applied to the area of carpet (i.e., kg/m^2 or lb/yd^2) must be converted to the units of the control mechanism, which is l/m^2 or gal/yd^2, through knowledge of the specific gravity of the emulsion. If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.

</td></tr>
</table>

BINDER CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Binder – Method B (Recommended for Random Checks)** ▪ Park the distributor on level ground and measure the number of liters or gallons of emulsion. Mark the locations of the front and back tires. ▪ Measure off a known distance for a test section. ▪ Have the distributor apply emulsion to the test section. ▪ Return the distributor to the original level ground and re-measure the number of liters or gallons of emulsion. ▪ Subtract the number liters or gallons after application from the original number of liters or gallons to obtain the number of liters or gallons applied. ▪ Divide the number of liters or gallons applied by number of square meters or square yards covered by emulsion to give the application rate in l/m^2 or gal/yd^2. ▪ If the distributor is not spraying the binder at the correct application rate, adjustments must be made to the controls and the process described above repeated until the correct application rate is achieved. Although this is the responsibility of the contractor, the inspector should verify that the distributor is spraying the binder at the correct application rate.

CHIP CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Chips – Method A (Recommended for Calibration)** ▪ Weigh a 0.84 m^2 (1 yd^2) tarp or geotextile material. ▪ Place the tarp or geotextile material on the roadway. ▪ Have the chip spreader apply the chips over the tarp or geotextile material. ▪ Weigh the tarp or the geotextile material with the chips. ▪ Subtract the original weight of the tarp or geotextile material from the weight of the tarp or geotextile with the chips. Divide the weight of the chips by the area of the tarp or geotextile to give the application rate in kg/m^2 or lb/yd^2.

CHIP CALIBRATION CONSIDERATIONS	
CHECKING APPLICATION RATES	**Chips – Method B (Recommended for Random Checks)** ▪ Weigh a haul truck empty. ▪ Load the haul truck with chips and reweigh the truck. ▪ Subtract the weight of the empty truck from that of the loaded truck to obtain the weight of the chips. ▪ Empty all the chips into the chip spreader. ▪ Have the chip spreader apply all of the chips from the weighed truck. ▪ Measure the length and width of the area over which the chips were spread. ▪ Divide the weight of the chips by the area over which they were spread to determine actual rate in kg/m^2 or lb/yd^2.
PROJECT INSPECTION RESPONSIBILITIES	
BINDER APPLICATION	▪ Is roofing felt or building paper used to start and stop binder application? ▪ Is the binder within the required application temperature range? ▪ Does the application look uniform? ▪ Are any nozzles plugged? ▪ Is there streaking in the applied binder? ▪ Are application rates randomly checked? ▪ Is the speed of the distributor adjusted to match the chip spreader to prevent stop-and-start operations? ▪ Is the distributor stopped if any problems are observed?
CHIP APPLICATION	▪ Are enough trucks on hand to maintain a steady supply of chips to the spreader? ▪ The application starts and stops with neat, straight edges? ▪ The binder application starts and stops on building paper or roofing felt? ▪ The chip spreader follows closely [30 m (33 yds) or less] behind the distributor when an emulsion is used? ▪ The chip spreader travels slowly enough to prevent chips from rolling when they hit the surface? ▪ Are the chips in a surface damp condition? ▪ No binder is on top of the chips? ▪ The application is stopped as soon as any problems are detected? ▪ Does the application appear uniform? ▪ Do the chips have a salt and pepper appearance? ▪ Check the percent chip embedment in the binder and adjust binder or chip application rate if required.

PROJECT INSPECTION RESPONSIBILITIES	
TRAFFIC CONTROL	▪ The signs and devices used match the traffic control plan? ▪ The work zone complies with Caltrans methods? ▪ Flaggers do not hold the traffic for extended periods of time? ▪ The pilot car leads traffic slowly — 40 kph (25 mph) or less—over fresh chip seals? ▪ Signs are removed when they no long apply? ▪ Any unsafe conditions are immediately reported to a supervisor?
ROLLING	▪ The rollers follow closely behind the chip spreader? ▪ The entire surface is rolled at least twice? ▪ Roller speeds kept at 5 mph (8-9 kph) maximum? ▪ The roller's first pass is on the meet line? ▪ Rollers do not drive on exposed emulsion? ▪ All stop, starts, and turns are made gradually?
TRUCK OPERATION	▪ Trucks travel slowly on the fresh seal? ▪ Stops and turns are made gradually? ▪ Truck operators avoid driving over exposed binder? ▪ Trucks stagger their wheel paths when backing into the chip spreader? This helps to eliminate chip roll over and aids in rolling.
LONGITUDINAL JOINTS	▪ The meet line is only as wide as the spray from the end nozzle—about 20 cm (8 in)? ▪ The distributor lines up so that the end nozzle sprays the meet line? ▪ The meet lines are not made in the wheel paths? ▪ The meet lines are made at the center of the road, center of a lane, or edge of a lane? ▪ The meet lines are not left uncovered overnight?
TRANSVERSE JOINTS	▪ All binder and chip applications begin and end on building paper or roofing felt? ▪ The building paper or roofing felt is disposed of properly?
BROOMING	▪ Brooming does not dislodge the aggregate? ▪ Brooming begins as soon as possible, but not until sufficient bond has formed between the chip and the binder? Check with the binder manufacturer for their recommendation or refer to agency requirements. ▪ Are misters on mobile pickup brooms operating?

PROJECT INSPECTION RESPONSIBILITIES	
OPENING THE CHIP SEAL TO TRAFFIC	▪ Traffic travels slowly–24 mph (40 kph) or less–over the fresh seal coat until the chip seal is broomed and opened for normal traffic? ▪ Reduced speed limit signs are used when pilot cars are not used? ▪ Are pavement markings placed before opening chip seal to normal traffic? ▪ Are all construction-related signs removed when opening chip seal to traffic and traffic control is removed?
CLEAN UP	▪ Is all loose aggregate from brooming removed from the roadway? ▪ Are binder spills cleaned up?